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A chronology of analytical assessments for Greenland Halibut in NAFO Subarea 2 & Divisions 3KLMNO

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Introduction

A brief history and chronology of analytical (VPA) assessments of this stock is provided to assist to the efforts of the ad-hoc WG on Assessment Methods for 2J3KLMNO Greenland Halibut.

XSA-based assessments have conducted by SC as the basis for providing advice during each of the 2000-2008 assessments. The assessments conducted during the 2000-2002 June SC meetings were all deemed to be "indicative of trends" in population dynamics, but unreliable with respect to absolute magnitudes of abundance, exploitable biomass and fishing mortality. In 2002, the XSA assessment was rejected by STACFIS. In 2003, the dataset used to calibrate the XSA was revised to include only post-1994 data. Subsequent assessments have made only minor alterations both to the XSA settings applied and the data used to calibrate the model. We provide a brief review of the annual assessments, and the rationale behind some of the important decisions taken surrounding the model settings applied and/or the data sets used to estimate stock status.

Attention is also given to alternate methodologies and/or sensitivity analyses conducted during these assessments, as a summary of this information may be of use in drafting a responses to pertinent requests from both the FC (Item 10a of FC Doc. 08/19) and from Canada (Item 3.3 of Canadian Request for Scientific Advice).

Analytical Assessments

The 1999 Scientific Council stock summary for Greenland Halibut in Sub-Area 2 and Divisions 3KLMNO indicated that "Analytical assessments are not possible with available data" (NAFO, 1999, p. 43). A recommendation was made by STACFIS to explore age-based analytical assessments during the year 2000 stock assessment (NAFO, 1999, p.167) pending the calculation of a total catch-at-age for NAFO Sub-Area 2 and Divisions 3KLMNO. These data were compiled, and reported in Bowering and Brodie (2000).

Below is a brief chronology of the focal points of the subsequent analytical assessments presented to Scientific Council. The earlier assessments are reviewed in greater detail as successive estimates of stock size were more volatile during this period.

2000 Assessment

Bowering et al. (2000) describe two ADAPT analyses (Gavaris, 1988) calibrated using survey data from the Canadian Fall surveys in Divs. 2J3K and EU summer surveys in Div. 3M. An initial analysis which assumed constant instantaneous natural mortality of M=0.2 resulted in strong residual patterns indicative of changing catchability in the Canadian data. To further explore the changing catchability, a second analysis was attempted which estimated natural mortality for ages 9 and older in all years. Estimating natural mortality was meant to "capture all factors affection removals from the population". This analysis yielded an estimate of M_{9+}=0.54;

however, there were high relative errors on some of the estimates of survivors and substantial correlation between some parameter estimates. Bowering et al. (2000) concluded: "The relatively large values for the correlation between parameter estimates suggest that the resulting model should not be used to make absolute projections without taking into account this correlation." They also expressed concern of the conversion of pre-1995 survey data to Campelen trawl equivalents for the youngest ages, and with the apparent change in survey catchability over time.

Darby and Mahé (2000) analyzed the new catch-at-age matrix with a separable VPA ($F_{a,y}$ as a combination constant selection at age and a fully exploited fishing mortality year effect) to investigate the structure of this data prior to its use in combination with survey data. They demonstrate that the residuals from an initial fit of the separable model indicated different selection patterns for the 1975-1987 and 1988-1999 periods, and describe gear changes in the fishery over that period which may support such a change.

The Extended Survivors Analysis model was also briefly described by Darby and Mahé (2000), and applied to catch data, the Canadian fall Div. 2J3K survey and the EU summer Div. 3M survey. A series of exploratory XSA analyses were conducted to find an optimum formulation. Strong patterns were evident in the Canadian fall survey catchability residuals, which led to further analysis in which the Canadian series was split into two, with separate catchability-at-age parameters fitted to the 1978-1987 and 1988-1999 data. Although improvements were noted, the overall fit was still deemed "relatively poor", and "the results of this assessment are considered to be indicative of trends in the stock dynamics rather than providing absolute estimates". Short and medium term projections were conducted and used as a basis to provide catch advice to Fisheries Commission (NAFO, 2000).

2001 Assessment

Several XSA analyses were conducted during the June 2001 SC meeting, building upon the XSA formulation accepted during the previous assessment. Mahé and Bowering (2001) conducted sensitivity analysis to evaluate the inclusion/exclusion of survey data at ages 1 and 2. Inclusion of this data decreased the magnitude of the retrospective recruitment estimates, and hence these data were retained in future analyses. Further sensitivity analyses on the impact of extending the number of years (from 2 to 5) to compute the mean fishing mortality towards which terminal population estimates are "shrunk". Analyses using a five-year shrinkage mean demonstrated reduced retrospective bias.

Hence, the final XSA was identical to that in the previous year, with the exception of:

a) inclusion of the age1 data from the EU Div. 3M survey. (During the 2000 assessment, ages 1 and 2 from the Canadian Div. 2J3K data were included in the XSA input data set, as were the age 2 data from the EU Div. 3M survey.), and
b) extending the number of years included in F-shrinkage from two to five.

Mahé and Bowering (2001) concluded that the results of the 2001 assessment were "still considered to be indicative of trends" in stock dynamics. Short and medium term projections assuming status quo fishing mortality were again provided as a basis for advice (NAFO, 2001).

2002 Assessment

An updated XSA analysis using the settings from the 2001 assessment with up-to-date catch and survey data "showed increases in the trends of catchability of both cpue's…and an increase in the retrospective pattern." (Mahé and Bowering, 2002). Investigation of residuals suggested that this analysis was overly influenced by the age 4-6 data from the Canadian survey. Hence, in order to reduce the relative weighting of these data points and lessen their dominance in estimation of terminal year survivors, the minimum standard error threshold was increased from 0.5 to 1.0, which improved the retrospective pattern in the final year of the analysis. Concern was expressed with the continued increase in the estimated biomass from XSA, which "was largely inconsistent with the major stock size indicators observed". It was concluded that the assessment was again "indicative of trends" only, and that "recent point estimates are …uncertain". Mahé and Bowering (2000) assert that it was "considered imprudent to formulate any projections from this assessment". Consequently, the XSA assessment was not accepted by STACFIS (NAFO, 2002).

Further exploration of the instability in the XSA results was reported by Darby et *al*. (2002).

2003 Assessment

An investigation of the consistency in the cohort information in the fishery-independent surveys as well as the consistency between the surveys and XSA results were provided by Darby et *al*. (2003). They noted "Low levels of internal and external correlation of the historic CAN RV0 (Canadian Fall surveys in Divs. 2J3K) indicate that it may be introducing noise to the assessment results."

An updated of XSA analysis using the 2002 assessment model formulation again yielded substantially different estimates of biomass compared to the year previous. The results were considered be more consistent with perceptions of stock dynamics inferred from surveys and commercial catch rates. Inconsistencies between the XSA and these data were the main reason for rejection of the 2002 assessment. A major change in the population estimates was the reduced numbers of survivors from the 1993-1997 year-classes. Darby et *al*. (2003) investigated potential mechanisms for the substantial one year revision in the estimates of the resource, concluding that the changes were primarily due to the addition of the 2002 catch and survey information: estimates of exploitable biomass in 2001 were halved when these data were included.

Darby et al. (2003) report that correlated residual patterns were found for both the EU summer and Canadian fall survey time-series, and postulate that such patterns could result from environmental changes or gear changes. Also, it was noted that the residual patterns coincide with a period of time when landings were both the largest on record and extremely uncertain due to suspected inaccuracies in catch reporting. The culmination of low internal/external correlations in the early survey data, the XSA retrospective pattern, correlations observed in the residuals and the potential explanation of this regarding catch reporting led to a revision to the survey data set used to calibrate the XSA. It was decided at the 2003 SC meeting that only survey data over the 1995-2002 period should be input to the XSA model. The revised formulation included the EU summer Div. 3M data, Canadian fall data from Divs. 2J3KL, and Canadian spring data from Divs. 3LNO. The resultant output was deemed to "show a marked improvement" in fit; the assessment was accepted by STACFIS and projections were conducted forming the basis for management advice.

Single-index analyses were conducted on the revised formulation to gauge the influence of each survey index on the revised model results (i.e. using all data), and the single index analyses were found to be consistent with the final run. Also, though not removed, the retrospective bias was lessened. To provide a measure of the uncertainty of the estimates, survey index residuals were bootstrapped and the XSA re-fitted to the bootstrapped data yielding (bias-corrected) percentiles of recruitment, exploitable biomass and average fishing mortality.

2004 Assessment

Investigations conducted during the 2004 SC assessment found that the 2003 XSA formulation was "still appropriate for fitting the model to the data" (Darby et *al*., 2004). In the course of arriving at this conclusion, the utility of using the pre-1995 data from Canadian fall surveys was re-visited. Exploratory analyses were conducted to investigate the sensitivity of model results to the inclusion of the earlier Canadian data, and the estimates of stock size and fishing mortality were of similar trend to the final run. Darby et al. (2004) reason that major changes in catchability due to a redistribution of Greenland Halibut from Divs. 2J3K to the deep waters of the Flemish pass preclude the inclusion of 1978-1994 Canadian survey data in the final model run.

Single-index sensitivity analyses were examined to explore the robustness of model estimates, with minimal difference in the trends or absolute values estimated from each of the three survey series (Canadian fall Divs. 2J3K, Canadian spring Divs. 3LNO and EU summer Div. 3M).

The sensitivity of model output to the maximum age included in the analysis was investigated as standard errors of the estimated catchability parameters for the oldest ages in the final model run were relatively large. Two XSA analyses with plus-groups combining ages 11+ and 12+ were compared to the final run (14+). Trends in estimates were common for each analysis, with some variations in average fishing mortality "resulting from sensitivity to the dome shaped exploitation pattern".

As STACFIS was unable to precisely estimate the total removals from this stock in 2003 (NAFO, 2003), a comparative analysis was undertaken to compare the results of assessments with three differing levels of total 2003 catch. Results yielded minor differences in the 2000-2004 estimates of exploitable biomass, yet curiously, substantial changes to the penultimate estimate of average fishing mortality.

Notable is the conclusion of Darby et *al.* (2004) regarding the sensitivity analyses:
"*The sensitivity analyses have shown that the XSA estimated trends in the stock dynamics are robust to the data series used for the fitting of the model, the inclusion or exclusion of the historic Canadian fall survey data, as a separate time series and the choice of plus group used for the analysis. Further, the alternate catch levels considered for 2003 do not alter perceptions of stock status.*

In addition to the XSA analyses, the 2004 assessment also included analytical assessments conducted within the ADAPTive framework (Gavaris, 1988) and estimated biomass dynamics using ASPIC software (Prager, 1994). It was found that the population estimates from ADAPT were in close agreement with the XSA assessment. The ASPIC results for the earliest biomass estimates seemed unreliable, but the most recent trends were also consistent with the biomass estimated using XSA.

Projections of the 2004 assessment were conducted assuming future catches equaled the 2004-2007 TACs established under the recent implemented stock re-building plan developed by the Fisheries Commission (NAFO, 2003)

2005 Assessment
An incomplete survey of Division 3L during the 2004 Canadian fall multi-species survey yielded estimated mean numbers per tow from Divs. 2J3KL that were not comparable to other years in this time-series. Subsequently, it was concluded that these data should not be used to calibrate the XSA (see Healey and Dwyer (2005)). The 2004 assessment was replicated but replacing the Div. 2J3KL index with a Div. 2J3K index over 1995-2003, with only minor differences in estimates of biomass and fishing mortality.

The 2005 SC assessment (Healey and Mahé (2005)) again affirmed that the XSA settings were most appropriate for estimating the dynamics of this stock. However, the 1995 data from the Canadian fall Div. 2J3K index were excluded from the estimation as it was noted the depth coverage of this survey was incomplete.

Given that the Spanish 3NO indices from the NAFO Regulatory Area had generally been consistent with other survey data for this stock, exploratory analyses which added this index to the tuning data set were conducted. Although the trends in results were similar to that excluding these data, the Spanish information was not retained in the final model owing to a general decreasing trend in the residuals for this index.

The robustness of the XSA model estimates to the shrinkage settings applied was investigated by conducting two additional analyses having less shrinkage. Both of the standard error values supplied by the user regarding shrinkage with respect to number of years used for mean F shrinkage and the mean F of younger ages applied to the oldest true age were set at 0.8. This was applied to the calibration data sets which included/excluded the 3NO-NRA Spanish data. Estimated results were very consistent in trend and magnitude for fishing mortality and exploitable biomass.

ADAPT analyses were also included in the 2005 assessment, with some attention given to the two types of F-constraints methods applied when a catch plus-group is used. Although some differences between the two ADAPT methods are noted, the differences amongst all ADAPT results and the final XSA run were in general relatively small.

2006 Assessment
During the 2006 June SC meeting, Gonzaléz Costas and Gonzaléz Troncoso (2006) provided an update of the consistency of the three survey series used to calibrate the XSA, and also the Spanish 3NO-NRA data (between/within survey correlations). They found that the within-index correlations indicated cohort-tracking consistency up to ages 5 to 6. Correlations were lower (sometimes negative) at older ages, a cause for concern.

Healey and Mahé (2006) updated the XSA analysis from the previous year, and reported "preliminary investigations indicated that the XSA settings used in the previous assessment were suitable". Due to ongoing concerns regarding the age-interpretations for this species, investigations into the number of ages modeled were repeated. A comparison of XSA analyses with plus-groups at ages 12+ and 13+ were compared to the 14+ plus-group used in the final XSA run indicated that "differences in estimated stock size were minimal".

This assessment also noted that the direction of the retrospective biases in estimated exploitable biomass and average fishing mortality had reversed over time and the extreme one-year revisions to the estimates of the 1997 and 1998 year-classes.

2007 Assessment
During data-screening analyses conducted during the 2007 assessment, (Healey and Mahé, 2007), attention was given to other available survey data that were not included in calibrating previous XSA assessments for this stock. In the end, it was decided that none of the additional data should be added to the calibration dataset (see Healey and Mahé (2007) for justification). The data-screening analysis also demonstrated that for several ages, the recent rate of increase in the Canadian fall Div. 2J3K mean numbers per tow data was not matched in either the Canadian spring Divs. 3LNO nor the EU summer Div. 3M data.

As in the previous assessment, preliminary analyses indicated that the XSA settings should remain unchanged in the 2007 assessment. However, residual problems continued to be evident, with strong evidence of cohort effects and an increasing trend in the Canadian fall survey data. Retrospective patterns were similar to those observed in the 2005 and 2006 assessments.

A series of "single-index" analyses were produced, and differences in recent estimates of recruitment between the analysis using EU data (only) and the Canadian fall data (only) were noted.

2008 Assessment
During the 2008 assessment, the final XSA run settings as applied in the previous assessment were deemed the best approach to modeling the catch and survey data (see Healey and Mahé, 2008). Residuals from this analysis were again problematic with evidence of year effects and cohort tracking. Further concern was expressed over the strong residual patterns in the recent Canadian fall survey data (most residuals over 2005-2007 are positive, with an increase in mean annual residual).

Two separate sensitivity analyses were conducted during the 2008 assessment. The single index analyses were again produced with similar findings to those noted for the 2007 assessment. Also the sensitivity of the results to the shrinkage settings (number of years and log Standard error threshold used to compute the F-shrinkage mean toward which population estimates are shrunk) were explored, as were the retrospective biases associated with the various choices for the shrinkage parameters. Healey and Mahé (2008) note that: "Comparisons of exploitable biomass, age 1 recruitment and average fishing mortality (Figure 17) indicate some differences in the recent time period. As expected, retrospective trends (Figure 18) increase as the influence of shrinkage is reduced. Also, residual patterns from these analyses (not shown) indicate that the residual problems in this assessment are worse for the low shrinkage runs."

Discussion and Summary

As documented in the previous section, many facets of both the input data used to calibrate the XSA and the model settings used to estimate population numbers have been continually scrutinized during assessments over the past decade. These have included examinations of the robustness of the estimates of exploitable biomass, age 1 recruitment and average fishing mortality, and in some cases, the retrospective biases, for:

- XSA analyses produced using only one survey series (described above as "single-index" runs),
- varied shrinkage parameters (number of years, number of ages, log standard error threshold),
- the number of ages explicitly modeled (by varying the plus-group age),
- inclusion/exclusion of various survey data (either survey series or particular ages),

and,

- varied levels of the total 2003 removals.

In general, each of these investigations have found that the trends in exploitable biomass and average fishing mortality were relatively insensitive across the alternative model settings or data sets considered. Thus, it may be argued that the XSA assessment of this stock has been internally consistent. Further, stock biomass estimates obtained from another VPA approach (ADAPT) and a biomass dynamics model (ASPIC) have been in agreement with the annual XSA assessments.

It is worth noting that some of this consistency may in fact be overstated. Variants of backwards projecting VPA models having sufficient catch history will – from the initial year to some point in time prior to the terminal year - converge to a common answer regardless of parameter settings or constraints applied to estimate the survivors in the terminal year. (The length of time required to attain this convergence is related to the relative magnitude of fishing mortality.) Hence, backwards projecting models may generate a false degree of comfort with the assessment results given this backwards convergence property. In this particular case, uncertainties in catch history over 1975-2008 may lead to convergence towards a biased result.

Notwithstanding the concerns raised in the previous paragraph, we consider that the XSA analysis as applied to Greenland Halibut in Sub-Area 2 and Divisions 3KLMNO is generally robust with respect to providing consistent estimates of exploitable biomass and average fishing mortality. The residual patterns and retrospective biases reported in the most recent assessments of this stock remain a cause of concern.

References

Bowering, W.R. and W.B. Brodie 2000. Calculation of Catch-at-Age for Commercially Caught Greenland Halibut in NAFO SubArea 2 and Divisions 3KLMNO during 1975-1999 with Particular Emphasis on Construction of the Catch-at-Age Matrix since 1989. NAFO SCR Doc. 00/24, Ser. No. N4253.

Bowering, W.R., W.B. Brodie, M.J. Morgan, D.Power, and D. Rivard. 2000. An Assessment of Greenland Halibut in NAFO Sub-Area 2 and Divisions 3KLMNO. NAFO SCR Doc. 00/43, Ser. No. N4274

Darby, C. and J.-C. Mahé. 2000. An Analysis of Stock Status of the Greenland Halibut in Sub-Area 2 and Divisions 3KLMNO Based on Extended Survivors Analysis. NAFO SCR Doc. 00/53, Ser. No. N4286.

Darby, C., R. Bowering, and J.-C. Mahé. 2002. Bullet Points on the Results of the Assessment Results for Greenland Halibut in Sub-Area 2 and Divisions 3KLMNO. NAFO SCR Doc. 02/81, Ser. No. N4696.

Darby, C., W.R. Bowering, and J.-C. Mahé. 2003. An Assessment of Stock Status of the Greenland Halibut Resource in NAFO Sub-Area 2 and Divisions 3KLMNO Based on Extended Survivors Analysis with Short and Medium-term Projections of Future Stock Development. NAFO SCR Doc. 03/64, Ser. No. N4883.

Darby, C.D., B.P. Healey, J.-C. Mahé, and W.R. Bowering. 2004. Greenland Halibut (Reinhardtius hippoglossoides) in Subarea 2 and Divisions 3KLMNO: An Assessment of Stock Status based on upon Extended Survivors Analysis, ADAPT, and ASPIC analyses, with stochastic projections of potential stock dynamics. NAFO SCR Doc. 04/55, Ser. No. N5008.

Gavaris, S. 1988. MS

Gonzaléz Costas and Gonzaléz Troncoso. 2006.

Healey, B.P. and K.S. Dwyer. 2004.

Healey, B.P. and J.-C. Mahé. 2005. An Assessment of Greenland Halibut in Subarea 2 + Divisions 3KLMNO, with Projections under the Fisheries Commission Rebuilding Plan. NAFO SCR Doc. 05/63, Ser. No. N5149.

Healey, B.P. and J.-C. Mahé. 2006. An Assessment of Greenland Halibut (Reinhardtius hippoglossoides) in Subarea 2 + Divisions 3KLMNO. NAFO SCR Doc. 06/51, Ser. No. N5281.

Healey, B.P. and J.-C. Mahé. 2007. An Assessment of Greenland Halibut (Reinhardtius hippoglossoides) in Subarea 2 + Divisions 3KLMNO. NAFO SCR Doc. 07/53, Ser. No. N5405.

Healey, B.P. and J.-C. Mahé. 2008. An Assessment of Greenland Halibut (Reinhardtius hippoglossoides) in Subarea 2 + Divisions 3KLMNO. NAFO SCR Doc. 08/48, Ser. No. N5xxx.

Mahé, J.-C., and W.R. Bowering. 2001. An Assessment of the Stock Status of the Greenland Halibut Resource in NAFO Sub-Area 2 and Divisions 3KLMNO based on Extended Survivors Analysis. NAFO SCR Doc. 01/80, Ser. No. N4459.

Mahé, J.-C., and W.R. Bowering. 2002. An Assessment of the Stock Status of the Greenland Halibut Resource in NAFO Sub-Area 2 and Divisions 3KLMNO based on Extended Survivors Analysis. NAFO SCR Doc. 02/78, Ser. No. N4692

NAFO 1999. Scientific Council Reports.

NAFO 2000. Scientific Council Reports.

NAFO 2001. Scientific Council Reports.

NAFO 2002. Scientific Council Reports.

NAFO 2003. Scientific Council Reports.